REPEATED SIDE-CUTTING KNEE & HIP BIOMECHANICS FOR A MACRO-CYCLE OF A PROFESSIONAL RUGBY LEAGUE SEASON.

By

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A Research Project submitted in partial fulfillment of the requirements of the University of Chester for the degree of M.Sc. Sports Sciences (Biomechanics).

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ABSTRACT:

The aim of this study was to determine the variability of lower-limb side-cutting biomechanics in professional rugby league players during a season. Thirteen male professional players were included with a mean age of 22 ±3.4 years. The study used a one-way repeated measures experimental design. Subjects were tested at three time points, separated by four weeks, over the last three months of a season. Peak knee valgus and internal rotation moments (Nm/kg^{-1}), and flexion angle (°), and hip abduction moment (Nm/kg^{-1}) during the weight-acceptance of the stance phase were collected for all side-cutting maneuvers. A one way repeated-measures ANOVA was performed on the data with Bonferroni post-hoc analysis identifying differences between testing sessions. Mean hip and knee kinematics and kinetics were similar for all measures. There was a significant difference in peak knee flexion angle (°) (Left = $F(1, 17) = 4.895$, Right = $F(2, 24) = 6.603$) and knee valgus moment (Nm/kg^{-1}) (Left = $F(2, 24) = 9.535$, Right = $F(2, 24) = 6.060$) showing significant variability between testing sessions one and three for right knee flexion and knee valgus in both limbs. Bi-lateral knee valgus moments were also significantly different between sessions two and three. Professional rugby league players have shown to be more efficient during the weight-acceptance phase of a side-cutting maneuver compared to recreational athletes which may be beneficial to reducing frontal plane knee loading and injury risk at the knee. In addition, this study has reinforced the link between the hip and the knee in providing proximal stability for distal mobility.

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INTRODUCTION:

Injury incidence in rugby league is amongst the highest of all professional sports, reporting in the region of 35-60 injuries per 1000 hours of play (Gibbs, 1993; Seward et al, 1993; Gissane et al, 1998). Consequently, the analysis of both extrinsic and intrinsic injury risk factors have been frequently reported, as they provide the key to development of any successful injury prevention strategy (Arnason et al, 2004; Gabbett & Domrow, 2005; Gabbe et al, 2006).

Assessment of lower limb kinetics and kinematics utilizing three-dimensional (3D) biomechanical models has become common practice in trying to understand the mechanisms underpinning lower limb injuries. Side-cutting has been highlighted as the most common of anterior cruciate ligament (ACL) injury inciting maneuvers (Boden et al, 2000; Agel et al, 2005; Renstrom et al, 2008) and is executed in a number of field sports repeatedly. Previous research on movement patterns of football players reported approximately 723 changes of direction were executed per game (Bloomfield et al, 2007; Keane et al, 2010; Green et al, 2011). The link between this maneuver and ACL injury has stimulated investigation but with no definitive conclusion regarding the exact underlying cause (McLean et al, 2004; Malinzak et al, 2001; Pollard et al, 2004; Sigward & Powers, 2006a; Demsey et al, 2007; Landry et al, 2007; Sanna & O'Conner, 2008; Vanrenterghem et al, 2010; 2012; Robinson & Vanrenterghem, 2012).

The ACL has been shown to be loaded by internal rotation and valgus deviation of the knee, as well as anterior tibial translation (Markolf et al, 1995;

Hame et al, 2002; Withrow et al, 2006; Dempsey et al, 2007). Large moments in these directions are well established risk factors associated with ACL injury. Literature also suggests that maximum loading of these metrics occurs during weight-acceptance of the stance phase and may therefore be indicative of the highest period of injury risk across the whole of the stance phase (Besier et al, 2001a, 2001b; Dempsey et al, 2007). Early cadaveric studies (Markolf et al, 1995; Hame et al, 2002), later reinforced by in-vivo studies (Olsen et al, 2004; Cochrane et al, 2007; Dempsey et al, 2007), have also found that increased knee flexion angle is associated with reduced frontal plane loading and therefore injury risk linked with abnormal valgus loading.

Whilst many of these studies have successfully identified a number of potential risk factors in 3D knee kinematics and kinetics, they have failed to come to a clear consensus, perhaps over-simplifying a complex phenomenon by trying to find a single underlying ‘key’ factor in only considering the knee (Hashemi et al, 2011). A number of studies have established that knee mechanics are also related to proximal and distal joint dynamics, suggesting that dysfunctional loading and ranges of motion at the knee may also be indicative of dysfunction at the ankle, hip and pelvis (McLean et al, 2004a; 2005; Pollard et al, 2004; 2007; Landry et al, 2007; Grimaldi, 2011; Sahrmann, 2011).

Side-cutting studies looking at the effects of hip kinematics on knee kinematics are, again, largely inconclusive (McLean et al, 1999; Malinzak et al, 2001; Pollard et al, 2004). However, hip dysfunction has been repeatedly suggested as an underlying cause of increased valgus loading in the ACL literature (Arendt & Dick, 1995; Griffin et al, 2000; Malinzak et al, 2001; Chappell et al, 2002; Pollard et al, 2005; Jacobs et al, 2007; McLean et al, 2007). Specifically, sufficient functioning of the hip abductor mechanism has been linked to optimal femoroplevic alignment in the frontal plane, balancing the loads medial to the center of rotation of the femoral head imposed by body mass and therefore ensuring ideal lower limb function (Fetto et al, 2002; Erceg, 2009; Grimaldi, 2011). This clearly warrants reporting of frontal plane moments at the hip and knee in side-cutting studies

In response to the suggested variation in side-cutting findings, Vanrenterghem et al, (2010; 2012) and Robinson and Vanrenterghem (2012), have recently found that ambiguity regarding joint axis definition, execution speed, task achievement and model definition could impact on the interpretation of previous studies. Vanrenterghem et al (2012) advocate standardization of approach speed (4m s^{-1}) to balance task achievement and injury risk and identify the most appropriate way to define joint axis according to investigator experience (Pohl et al, 2010). These guidelines encourage a more standardized approach to side-cutting research and allow more confident comparability across studies.

Currently, there are a limited number of studies relating to the reliability of biomechanical parameters during the task of side-cutting. These studies used varied analytical methods including intra-class correlation coefficients (ICC) (Ford et al, 2007; Houck et al, 2006; Marshall et al, 2014), coefficients of multiple correlations (CMC) (Sigward & Powers, 2006a; 2006b) and coefficients of multiple determinants (R^2) (Besier et al, 2001b). As well as variation in their choice of analysis, different strengths and components of statistical reliability have been reported. For example, Marshall et al (2014) reported excellent within-session reliability (ICC>0.75) for ankle, knee, hip and trunk kinematics during 75° side-cutting. The kinetic measures were not so reliable in the frontal plane, with hip abductor and knee varus moments being poor (ICC<0.4) (Ford et al, 2007). Sigward and Powers (2006a; 2006b) found frontal (CMC = 0.90) and transverse (CMC = 0.93) plane kinetics to be more reliable between sessions than the respective kinematics during a 45° side-cut (Frontal CMC = 0.63, Transverse CMC = 0.61). Finally, Besier et al (2001b) reported both within and between-session reliability during 30° and 60° side cutting. The lowest within and between-session reliability scores being for transverse (average R^2 = 0.84 ± 0.09) and saggital (average R^2 = 0.89 ± 0.04) knee moments respectively.

Reliable joint kinetics and kinematics are distinguished by small within-, between-session and intra- and inter-therapist variability (Schwartz et al, 2005; Deschamps et al, 2012). Despite some inconsistencies in their findings, the results of the above studies generally suggest that biomechanical side-cutting parameters have both good within- and between-session reliability, however they do not consider intra- and inter-therapist effects. The most concerning findings are those reported by Marshall et al (2014) regarding hip abductor and knee varus moments, although the poor reliability (ICC<0.4) of these measures could be explained by the use of peak values and ICC. These limit data to specific time points of the stance phase, they do not consider the temporal aspect of waveforms across the time series of a side-cutting trace and may influence the interpretation (Pataky, 2012; Malfait et al, 2014; Sankey et al; 2015).

Consideration of variability on the process of clinical interpretation is important, whether this is indicative of injury or actually an important part of motor control and performance (Butler et al, 2003; Bosch & Klomp, 2005; Pollard et al, 2005). There is some evidence to suggest that coordination variability around a joint provides flexibility in response to perturbations and unplanned movements and is essential to maintaining healthy movement patterns (Hamill et al, 1999; Heiderscheit et al, 2002). A reduction in coordination variability has been observed in patients with patella-femoral pain and females during unanticipated side cutting, their healthy and male counterparts respectively, demonstrating more variability (Hamill et al, 1999; Heiderscheit et al, 2002). It is possible that exhibition of less coordination variability around a joint could be indicative of an injury or potential injury state.

The performance of side-cutting in an elite sporting population is both scarce and not well understood. Despite being commonly used as an assessment tool for ACL injury risk, the current literature provides little insight into the reliability of side-cutting data or the variability within commonly used protocols making it hard to interpret injury risk (Sankey et al, 2015). There is currently an absence of biomechanical data in professional rugby league, but epidemiology studies are becoming more prevalent. The injury data for a Superleague club in 2013 was a total of 68 injuries, 46 of which were lower limb (Figure 1). Surprisingly, with rugby league being a contact sport, there were a large proportion of non-contact injuries (41%) (A Naylor, personal communication, 3rd March 2014). There is also suggestion of an increase in injuries sustained during the latter stages of an amateur rugby league season. It is hypothesised that this maybe due to fatigue or accumulative microtrauma (Gabbett et al, 2000; 2003).

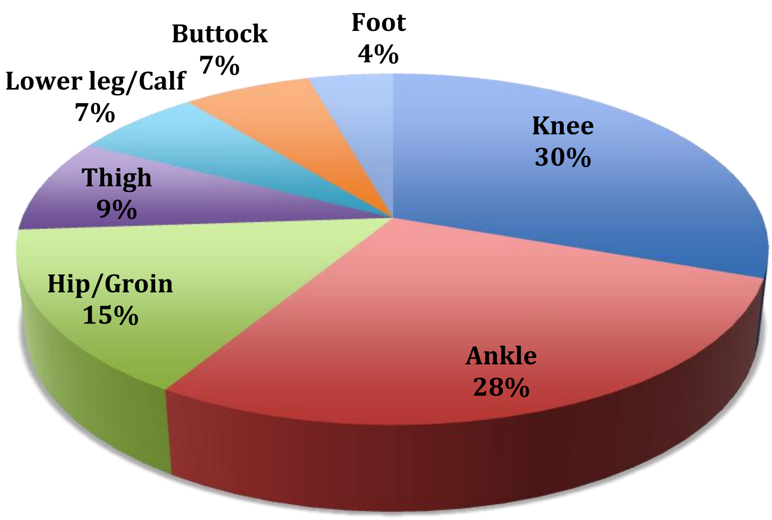

Figure 1 – Location of lower limb injuries at a selected Superleague club 2013.

The aim of this study will be to determine the variability of lower-limb side-cutting biomechanics in professional rugby league players over the course of a season (3 micro-cycles). It is hypothesized that there will be significant ($p<0.05$) differences in peak knee kinetics (valgus and internal rotation moments) and kinematics (knee flexion angle) and hip kinetics (hip abduction moment) during the weight-acceptance phase of side-cutting maneuver, between the last three months of a domestic season.

METHOD:

Participants:

Thirteen male professional rugby league players consented to participate in this study (mean age = 22 ±3.4 years, mean body-weight = 97.1 ±8.1 kg, mean height = 184.2 ±5.2 cm). Volunteers were recruited through a presentation (Appendix 1) given to all of a named 2016 European Superleague first team squad (N=32). Subjects were injury-free at the time of assessment, defined as fit-for-selection in the week prior to scheduled testing by the lead investigator who is a Chartered Physiotherapist registered with the Health Professionals Council. One subject was excluded from the study because of previous ACL surgery and three subjects withdrew as they sustained injuries during match-play over the course of the study. Ethical approval for the study was granted by Dr Stephen Fallows of Chester Universities Faculty Research Ethics Committee on 15th July 2014 (Appendix 2). Prior to participation, all subjects read and signed the informed consent forms. Participants were informed they could withdraw at any time without giving any reason when they were recruited.

Design:

Data was collected by one observer using a one-way repeated measure (time) experimental design. Subjects (n=13) were tested on three separate occasions, separated by four weeks, over the course of a domestic Superleague season. The time period between tests coincided with the training micro-cycles of the squads in-season training program (Appendix 3).

A priori calculation using an effect size of 0.5 to detect a moderate effect was used as opposed to the large effect size (0.8) observed during side-cutting studies using amateur athletes due to assumed superior side-cutting proficiency in this professional cohort (Besier et al, 2001a; Malinzak et al, 2001; Pollard et al, 2004; Dempsey et al, 2007). G Power software (version 3.19) suggested a sample of 12 was required for an 80% power and alpha of $p < 0.05$ (Faul et al, 2007; 2009).

Peak knee valgus and internal rotation moments (Nm/kg^{-1}), and flexion angle (°); and hip abduction moment (Nm/kg^{-1}) during the weight-acceptance of the stance phase were collected for all side-cutting maneuvers.

Procedures

Subjects wore tight fitting lycra and their usual indoor training footwear. To aid speed of analysis two other chartered physiotherapists assisted on the days of data collection, supervising a standardized warm-up and applying the anatomical markers according to the “Lower Limb and Trunk” (LLT) Model defined by Vanrenterghem et al (2010) (Appendix 4).

On each testing occasion, subjects completed six randomly selected 45° side-cut maneuvers. These were evenly distributed between the left and right leg and at a constant speed of 4 ms^{-1} (Pohl et al, 2010). Approach speed was monitored using Smart Cell photocell timing gates (Fusion Sport, Cardiff, UK) positioned 2m apart and 2m from the force plate where the cut was to be executed (Appendix 5). A trial was deemed valid if the approach speed fell between 3.8 and 4.2 ms^{-1} ($^{+/-}$ 5%) and all of stance phase of the pivot limb was recorded on the designated force-plate. Participant feedback was standardised to being “good” if it fell within these speed parameters, anything above or below this were feedback as being “too fast” or “too slow” respectively. Prior to the trials subjects completed a generic 10 minute Watt Bike aerobic warm-up (Watt Bike Ltd, Nottingham, UK) and three side-cutting efforts in each direction as familiarization to the required approach speed and execution (Vanrenterghem et al, 2010, 2012; Robinson and Vanrenterghem, 2012). During the familiarization, subjects were advised to try and ensure they did not adjust their stride pattern in their approach to the force plate and to side-cut as they would in a game or training. No further coaching or de-brief on performance was offered.

Data was collected by the lead researcher of this study in a Biomechanics Lab and subjects visited three times over the duration of the study (3 micro-cyles). Each side-cut was executed on a 0.9 x 0.6 m^2 Kistler force platform (Kistler Instruments Ltd, Winterhur, Switzerland) sampling at a frequency of 1000Hz and measuring ground reaction force. The 45° cutting angle was clearly marked on the platform with tape and a marker to the left and right put out to provide subjects with a visual cue of the required exit direction (Appendix 5). Ground reaction force and kinematic data were simultaneously recorded in Qualisys Track Manager (Version 2.13, Qualisys AB, Gothenburg, Sweden) using 8 optoelectronic cameras (Oqus 3, Qualisys AB, Gothenburg, Sweden) sampling at a frequency of 250Hz.

Biomechanical Model:

This study used the Liverpool John Moores LLT model as described in Vanrenterghem et al (2010) (Appendix 4). Segmental coordinate systems were defined according to the University of Western Australia model (Besier et al, 2003), using individual trials for anatomical calibration (Cappozzo et al, 1995), and for calculating functional hip joint centres (Schwartz and Rozumalski, 2005) and functional knee joint axis (Besier et al, 2003).

Data Analysis:

Kinematic and inverse dynamic calculations were performed in the software Visual 3D (Version 5, C-Motion, Leicester, UK) and utilized. As suggested by Kristianslund et al (2012) both kinematic and kinetic data were processed with the same filter and cut-off frequency. A 4th order low pass Butterworth filter (Robertson et al, 2004; Dempsey et al, 2007) was applied, with a cut-off frequency of 20 Hz determined through residual analysis (Robertson et al, 2004; Winter, 2009).

Following tests for normality (Shapiro-Wilk) and sphericty (Mauchly's) a one way repeated-measures ANOVA was performed between the three sets of data. When sphericity was untrue (left knee flexion and internal rotation), a Greenhouse-Geisser adjustment was made prior to the ANOVA to modify the degrees of freedom so that a valid F-ratio could be obtained. (Robertson et al, 2004). An alpha level of $p<0.05$ was set and when a significant difference observed, a Bonferroni post-hoc analysis was carried out for bilateral knee flexion and valgus to identify between which testing sessions the difference exists. All statistical procedures and analysis were performed using SPSS 21.0 (SPSS Inc, Chicago, IL) (Appendix 6).

RESULTS:

Mean (± standard deviation) transverse plane whole body centre of mass velocities at touch-down are presented in Table 1. There was a relatively good match between this (Left: 4.49 ± 0.43; Right: 4.4 ± 0.42 ms^{-1}) and the defined entry speed according to the speed gates at the time of testing (3.8 and 4.2 ms^{-1}) (Fusion Sport, Cardiff, UK).

Table 1. Centre of mass velocities at touch-down & angle of exit at toe-off.

Side	COMV Mean (ms^{-1})	COMV Std. Deviation	Angle TO Mean (°)	Angle TO SD (°)
L	4.49	0.43	28.82	3.37
R	4.4	0.42	29.04	2.71

In light of the recommendations made by Vanrenterghem (2012) in the reporting of task execution, this study reported comparable mean toe-off angles of 28.8 (± 3.37)° and 29.04 (± 2.71)° for side-cutting left and right at 4 ms^{-1} in comparison to an amateur female population (31.8 ± 2.7).

The mean hip and knee kinematics and kinetics (± standard deviation) for this study are presented in table 2. The mean hip and knee kinematics and kinetics were similar between left and right sides for all measures.

Table 2. Mean hip and knee kinetics and kinematics.

Variable	Metric	LL	Mean	Std.Deviation
Knee Flexion Angle	Degrees	L	-43.22	6.74
		R	-42.05	5.94
Knee Valgus Moment	Nm/Kg^{-1}	L	-0.21	0.14
		R	-0.18	0.15
Hip Abduction Moment	Nm/Kg^{-1}	L	0.72	0.41
		R	0.70	0.40
Knee Internal Rotation Moment	Nm/Kg^{-1}	L	1.19	0.47
		R	1.09	0.39

There was a significant difference ($p<0.05$) in peak knee flexion angle (°) (L=$F(1, 17)=4.895$, R=$F(2, 24)=6.603$) and knee valgus moment (Nm/kg^{-1}) (L=$F(2, 24)=9.535$, R=$F(2, 24)=6.060$) suggesting variability between testing sessions. There was no significant difference in hip abduction and knee internal rotation moments (Nm/kg^{-1}). These results were consistent for both the left and the right lower limb (Table 3).

*Table 3. Outcome measures tests for Sphericity and one-way repeated ANOVA. *Greenhouse-Gessier adjustment used.*

Variable	Metric	Side	F	P-value*
Knee Flexion Angle	Degrees	L	4.895	0.032*
		R	6.603	0.005
Knee Valgus Moment	Nm/Kg^{-1}	L	9.535	0.001
		R	6.060	0.007
Hip Abduction Moment	Nm/Kg^{-1}	L	2.892	0.075
		R	1.496	0.244
Knee Internal Rotation Moment	Nm/Kg^{-1}	L	2.766	0.110*
		R	1.096	0.35

Bonferroni post-hoc analyses (Table 4) showed that there was significant variability between testing sessions 1 and 3 consistent for right knee flexion (p=0.025) and knee valgus in both limbs (L: p=0.013, R: p=0.024). Bi-lateral knee valgus moments were also significantly different (L: p=0.004, R: p=0.038) between sessions two and three.

Table 4. Bonferroni post-hoc analyses for knee flexion and valgus testing sessions 1, 2 and 3.

Variable	Side	Session Numbers	Mean Difference	Significance (p)
Knee Flexion Angle	L	1 & 2	-3.326	0.376
		2 & 3	-2.943	0.123
		1 & 3	-6.269	0.085
	R	1 & 2	-2.792	0.412
		2 & 3	-3.854	0.104
		1 & 3	-6.646	0.025
Knee Valgus Moment	L	1 & 2	-0.042	1
		2 & 3	-0.132	0.004
		1 & 3	-0.174	0.013
	R	1 & 2	0.01	1
		2 & 3	-0.167	0.038
		1 & 3	-0.157	0.024

A post-hoc power calculation to determine the probability of error for the reported results was completed. Using the lowest F-value (metric: value) to ensure the study is powered to detect an effect, G Power software (version 3.19) suggests a power value of 0.11 was calculated (software details). This means that this data has a 11% probablility of making a type II error, a well powered study according to the 20% cut-off reported by Field (2005).

DISCUSSION:

The primary objective of this study was to investigate the variability of specific hip and knee kinetics and kinematics during side-cutting over the course of a Rugby League season and to provide normative kinetic and kinematic data for an elite athlete cohort. The mean values for all variables were relatively symmetrical between limbs irrespective of leg dominance (Table 1) and this is in line with contemporary literature findings (Malinzak et al, 2001; Robinson and Vanrenterghem, 2012). Despite limb symmetry and comparable execution proficiency relating to task execution (Table 1) (Vanrenterghem et al, 2012), there are a number of differences in metrics for this sample in comparison to current evidence.

This study reported mean peak knee valgus moments of 0.2 Nm/kg^{-1}. This figure is significantly lower than 0.58 Nm/kg^{-1} reported by Vanrenterghem et al (2012) at an identical speed and 0.31 $^{+}/_{-}$ 0.1 Nm/kg^{-1} reported by Pollard et al (2004) at approach speeds of 5.5-6.5 $m\ s^{-1}$. The observed mean value in this study is more reflective of the loading Vanrenterghem et al (2012) observed at 3 $m\ s^{-1}$. Mean hip abduction moments (0.71 ± 0.4) were also less than those reported by Pollard et al (2004) (0.96 ± 0.3) at faster speeds. The main explanation for this assumed higher functioning, lower loading at faster speeds, could relate to the elite nature or conditioning age of the sample population. The other studies (Pollard et al, 2004; Vanretgerghem et al, 2012) used male and female recreational athletes who you would not expect to be as technically proficient as their professional counter parts. (Pollard et al, 2004; Bloomfield et al, 2007; Gabbett et al, 2011).

In addition, the reduced frontal plane moments (knee valgus) could be explained by the coupled knee flexion range of movement (mean 42.63 ± 6.34) observed in this study. This is significantly higher than the values observed during weight-acceptance in a number of other prominent side-cutting studies at speeds ranging from 2 to 6.5 m s^{-1}; 20-30° (Malinzak et al, 2001), 10-20° (Pollard et al, 2004), 25.4° ($^{+}/_{-}$ 10.3) (Sanna & O'Conner, 2008) and 13-19° (Vanrenterghem et al, 2012). The increased knee flexion could have acted as a deceleration function, reducing the expected frontal plane loading seen in other studies (Pollard et al, 2004; Vanrenterghem et al, 2012). It could also be due to the absence of pre-stance flexion observed by Vanrenterghem et al (2012). They hypothesize that speed-related knee flexion adaptations may occur in preparation for stance, similar to the proven feed-forward action of the deep abdominals in preparation for peripheral joint movement (Kibler et al, 2006; Vasseljen et al, 2012). This could not be validated because this action fell outside of the calibrated motion capture volume. Although limited by the same issues in this study, it is suggested that elite athletes may not require this pre-stance movement, executing it all at heel strike and explaining the higher levels of knee flexion. Cadaveric (Markolf et al, 1995; Hame et al, 2002) and in-vivo (Olsen et al, 2004; Cochrane et al, 2007; Dempsey et al, 2007) studies have also indicated that increasing knee flexion angle may reduce loading at the knee and also injury risk, which reinforces the aforementioned hypothesis and is indicative that elite athletes may have adopted more proficient ways of side cutting.

The only kinetic metric to exceed torques reported in the literature was knee internal rotation (1.14 ± 0.43 Nm/kg^{-1}), with an average mean peak value of 110.69 Nm. This was over 30 Nm greater than that observed in the Monte Model (35-80 Nm) (Markolf et al, 1995; Kanamori et al, 2000; McLean et al, 2004). The consistency of this observation in the sample population is suggestive that these athletes have either a greater neuromuscular capacity to generate and absorb such force or utilize a different pattern of side-cutting to recreational athletes of either gender.

Few studies have considered the hip along with knee metrics. This study reinforces the current trend of "proximal stability for distal mobility" (Putnam, 1993; Kibler et al, 2006; Hibbs et al, 2008), non-significant variability in hip abduction moments (L: p=0.075, R: p=0.244) and significant variability in knee valgus moments (L: p=0.001, R: p=0.007). This combined with the coincidental absence of knee injury history amongst this cohort of elite rugby league players is suggestive of a relationship, adding further credence to current thinking around lower limb biomechanics and injury and that variability maybe an important element of motor control (Butler et al, 2003; Bosch and Klomp, 2005; Pollard et al, 2005). In addition, biomechanical research investigating optimal performance of the lower extremeties have also started to utilize the concept of stiffness. In the human body this is considered as the combined total of the individual components contributing to stiffness; tendons, muscles, bones, cartilage and ligaments (Latash and Zatsiorsky, 1993, Butler et al, 2003). Specifically, this may manifest itself in-terms of observed peak vertical ground reaction forces, joint loading and range of motion (Granata et al, 2001; Williams et al, 2000). If considering this phenomenon, we may start to consider reduced variability as stiffness and perhaps an important factor for some joints like the hip but not the knee, Further research into specific correlations between the hip and knee need to be completed to understand whether we are over-simplifying a complex phenomenon in lower limb injury prevention and understanding (Hashemi et al, 2011).

Post-hoc analysis showed significant knee kinematic and kinetic variability in both the saggital and frontal plane across testing sessions. Hip abduction and knee internal rotation moments did not show any significant difference. Right knee flexion angle was significantly different between sessions one and three. Although not significantly significant the left knee showed a similar difference between the same testing sessions. Bilateral knee valgus was significantly different between trials one and three and between trials two and three. Evident in this discussion is the large volume of research addressing the importance variability plays in interpreting biomechanical findings, especially in response to any clinical interventions (Vanrenterghem et al, 2010; 2102; Robinson and Vanrenterghem, 2012; Malfait et al, 2014, Sankey et al, 2015). The current reported inter-session variability (knee flexion and knee valgus) or lack of it (Hip abduction and knee internal rotation) could help to guide interpretation of the effect of various interventions for the same metrics if all other elements of a studies design are the same (Malfait et al, 2014).

To put these variability findings into clinical context, cadaveric studies combining ground reaction forces and joint and muscle mechanics using modeling techniques, have found valgus loads of 125-201Nm will cause ACL damage (Piziali et al, 1980). If considering the average peak value of 0.2 Nm/kg^{-1} which equates to 19.42 Nm for the average player, the variability described (0.132-0.167 Nm/kg^{-1}) (Table 4) is not of a magnitude to be of clinical concern or highlight any potential increased injury risk.

When considering the potential sources of inter-session variability for knee flexion and knee valgus, it is easy to associate the dynamic nature of the side-cut as the source for such observations. For example, within-subject technical proficiency and therefore ability to reproduce consistency in skill execution, may elicit variable knee kinematics and kinetics during weight-acceptance of the stance phase. This hypothesis is negated not only by the elite cohort and their assumed technical excellence but also by the consistent moments reported for hip abduction and knee internal rotation across the three testing sessions. Consequently, it is reasonable to consider other potential causes of these findings. Gabbett et al (2000; 2003) states that injuries in professional rugby league manifest themselves in the latter half of the season potentially due to inadequate recovery between games and training and a resultant cumulative fatigue.

There is an absence of data relating to longitudinal studies relating to chronic central fatigue (Welsh et al, 2002) but the impact of acute fatigue on joint dynamics during functional sporting tasks have been well reported (Nyland et al, 1994; Rodacki et al, 2001; Fagenbaum and Darling, 2003; Chappell et al, 2005; Coventry et al, 2006; McLean et al, 2007; Sanna et al, 2008; Borotikar et al, 2008). The literature regarding knee flexion and internal rotation is inconsistent. Previous studies have found knee flexion to reduce significantly after fatigue (Rodacki et al, 2001; Chappell et al, 2005) while others have reported no effect at all (Nyland et al, 1994; Fagenbaum and Darling, 2003; Chappell et al, 2005; Coventry et al, 2006; McLean et al, 2007). Similarly, knee internal rotation moments have been shown to accentuate under fatigue (Nyland et al, 1997; Chappell et al, 2005; McLean et al, 2007) but also to remain stable (Sanna et al, 2008). The observed disparity in reported biomechanical changes as a result of fatigue are likely to relate to two major flaws in their design; the fatigue protocols used and differences in the tasks being analysed. Irrespective, this studies findings over the final 3 months of the European Superleague season and epidemiology literatures strong links between fatigue, injury and changes in both saggital and transverse plane knee kinetics and kinematics are clear in the studies relating to these topics (Gabbett et al, 2000; 2003).

Limitations:

This study identified the weight-acceptance phase of a side-cut as the discrete time point for which the hip and knee metrics were to be taken. Therefore, we must understand that these values only apply to this specific phase of stance. Whether this variability applies across the remaining phase of a side cut needs to be investigated and is now possible with the use of one-dimensional statistical parametric mapping, a method of objectively analyzing the entire stance phase (Pataky, 2012; Vanrenterghem et al, 2012). It should be noted that waveform kinetic data variability has been reported to be distinctly raised to higher extents during the weight acceptance phase in comparison to other part of the stance time series, in addition it is also where injury is thought to occur (Besier et al, 2001a, 2001b; Dempsey et al, 2007; Sankey et al, 2015). This reinforces the choice of this time point when discussing variability in this study.

Conclusion:

In conclusion, this is the first study to report knee and hip kinetic and kinematic data for professional rugby league players (N=13) during the weight-acceptance phase of a side-cutting maneuver over the duration of a three month in-season macrocycle. Utilising a standardized model and data processing techniques (Vanrenterghem et al, 2010; 2012; Robinson and Vanrenterghem, 2012), this particular elite cohort have shown to be more efficient during this phase of the side cut with reduced moments at the hip and knee in comparison to recreational counterparts. However, they do appear to adopt a different movement pattern utilizing increased knee flexion and greater neuromuscular capacity, beneficial to reduced frontal plane loading and injury risk at the knee. The concept of proximal stability for distal mobility is also reinforced by this study, with hip abduction showing non-significant variability and knee valgus showing significant variability.

Variability in knee flexion (°) and valgus (Nm) showed a consistent difference between the first and second and first and third testing session (Table 4), indicative of a potential influence of central fatigue in light of the findings of

Gabbett et al (2000; 2003) regarding an increase in injury epidemiology in the latter half of a season.

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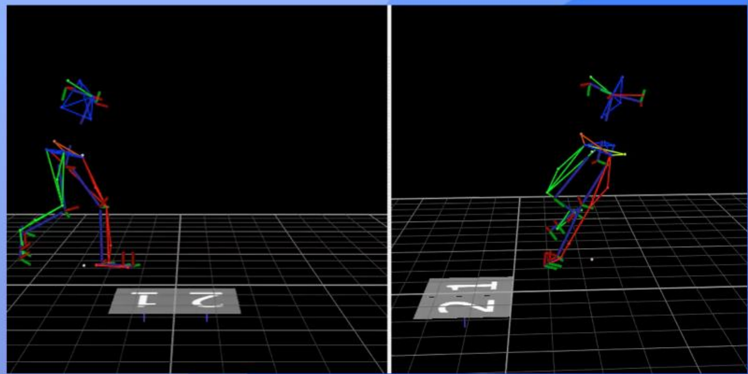
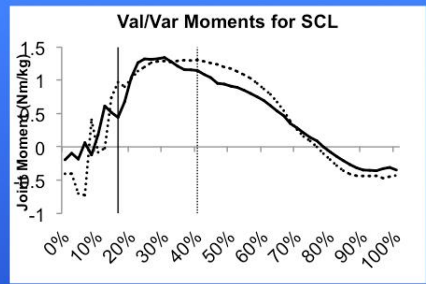
Appendix 1: Study recruitment presentation

Side-stepping in RL: A study of biomechanics





- Number of participants needed: 12 or >
- How much commitment is needed: 3 testing sessions lasting 30 mins
- Purpose of the study: To understand lower limb mechanics in professional rugby league players
- Why me: Currently no research in this area, first in sport/Superleague
- What are the risks: None, injury risk no greater than training
- Benefits: Increased understanding of how you move & potential changes in training and rehabilitation.
- Do I have to take part: No, completely your decision
- If I am interested: Collect an information sheet & consent form.

Appendix 2: Ethical Approval Documentation

Faculty of Life Sciences
Research Ethics Committee

frec@chester.ac.uk

Ben Stirling
Grappenhall
Warrington

15th July 2014

Dear Ben,

Study title:	**Knee and hip biomechanics in a repeated side-cutting task during a macrcycle of a professional rugby league season.**
FREC reference:	**918/14/BS/SES**
Version number:	**1**

Thank you for providing the documentation for the further amendment recommended following the approval of the above application. This amendment has been approved by the Faculty Research Ethics Committee.

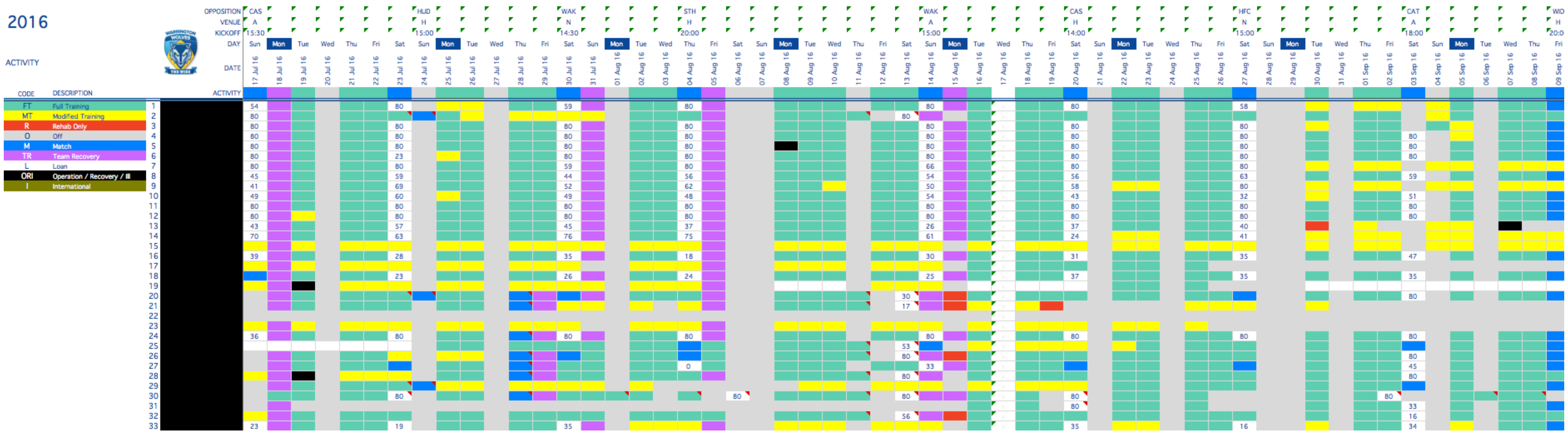
- Participant Information Sheet, version 2

With the Committee's best wishes for the success of this project.

Yours sincerely,

Dr. Stephen Fallows
Chair, Faculty Research Ethics Committee

Appendix 3: Training Microcycle: Schedule



Appendix 3: Training Microcycle: Training load

2016

DAILY INTENSITY
0-10 Scale
(arbitrary value)

	28 Jul 16	29 Jul 16	30 Jul 16	31 Jul 16	01 Aug 16	02 Aug 16	03 Aug 16	04 Aug 16	05 Aug 16	06 Aug 16	07 Aug 16	08 Aug 16	09 Aug 16
OPPOSITION			WAK					STH					
VENUE			N					H					
KICKOFF			14:30					20:00					
DAY	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
INTENSITY	1.6	1.4	5.8	0.0	0.0	1.5	1.2	6.6	0.0	0.0	0.0	1.6	3.6
Accs	2	2	6	0	0	2	2	7	0	0	0	3	6
Decs	1	1	5	0	0	1	1	6	0	0	0	1	3
DSL	1	1	8	0	0	1	1	8	0	0	0	1	3
HML	1	1	4	0	0	1	0	4	0	0	0	1	3
JSS	2	2	7	0	0	3	1	8	0	0	0	2	3

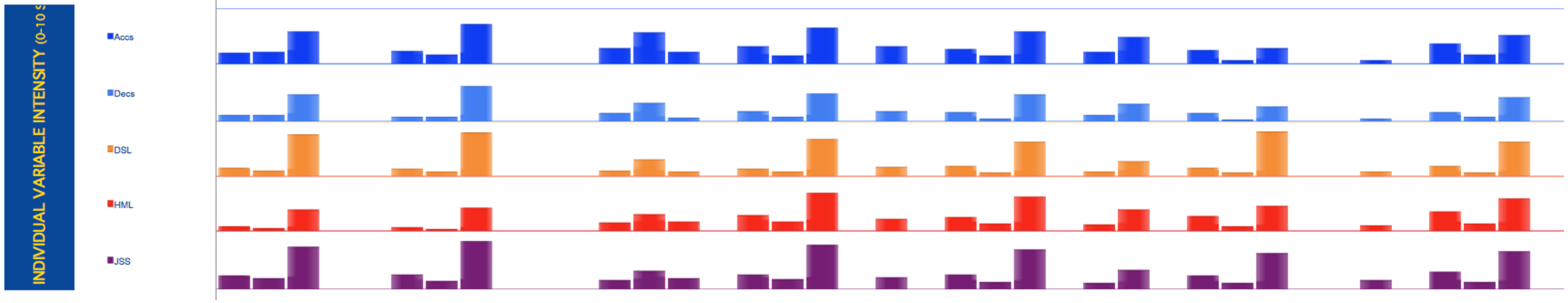
	10 Aug 16	11 Aug 16	12 Aug 16	13 Aug 16	14 Aug 16	15 Aug 16	16 Aug 16	17 Aug 16	18 Aug 16	19 Aug 16	20 Aug 16	21 Aug 16	22 Aug 16
OPPOSITION					WAK						CAS		
VENUE					A						H		
KICKOFF					15:00						14:00		
DAY	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon
INTENSITY	1.5	0.0	2.3	1.3	6.4	0.0	2.2	0.0	2.4	1.3	6.2	0.0	1.5
Accs	2	0	3	2	6	0	3	0	3	1	6	0	2
Decs	1	0	2	1	5	0	2	0	2	0	5	0	1
DSL	1	0	1	1	7	0	2	0	2	1	6	0	1
HML	2	0	3	2	7	0	2	0	2	1	6	0	1
JSS	2	0	3	2	7	0	2	0	3	1	7	0	1

	23 Aug 16	24 Aug 16	25 Aug 16	26 Aug 16	27 Aug 16	28 Aug 16	29 Aug 16	30 Aug 16	31 Aug 16	01 Sep 16	02 Sep 16	03 Sep 16	04 Sep 16
OPPOSITION					HFC							CAT	
VENUE					N							A	
KICKOFF					15:00							18:00	
DAY	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
INTENSITY	3.8	0.0	2.4	0.9	4.8	0.0	0.0	1.0	0.0	3.0	1.4	5.9	0.0
Accs	5	0	2	1	3	0	0	1	0	4	2	5	0
Decs	3	0	1	0	2	0	0	0	0	2	1	4	0
DSL	3	0	2	1	8	0	0	1	0	2	1	6	0
HML	4	0	3	1	4	0	0	1	0	4	1	6	0
JSS	3	0	2	1	6	0	0	2	0	3	1	6	0

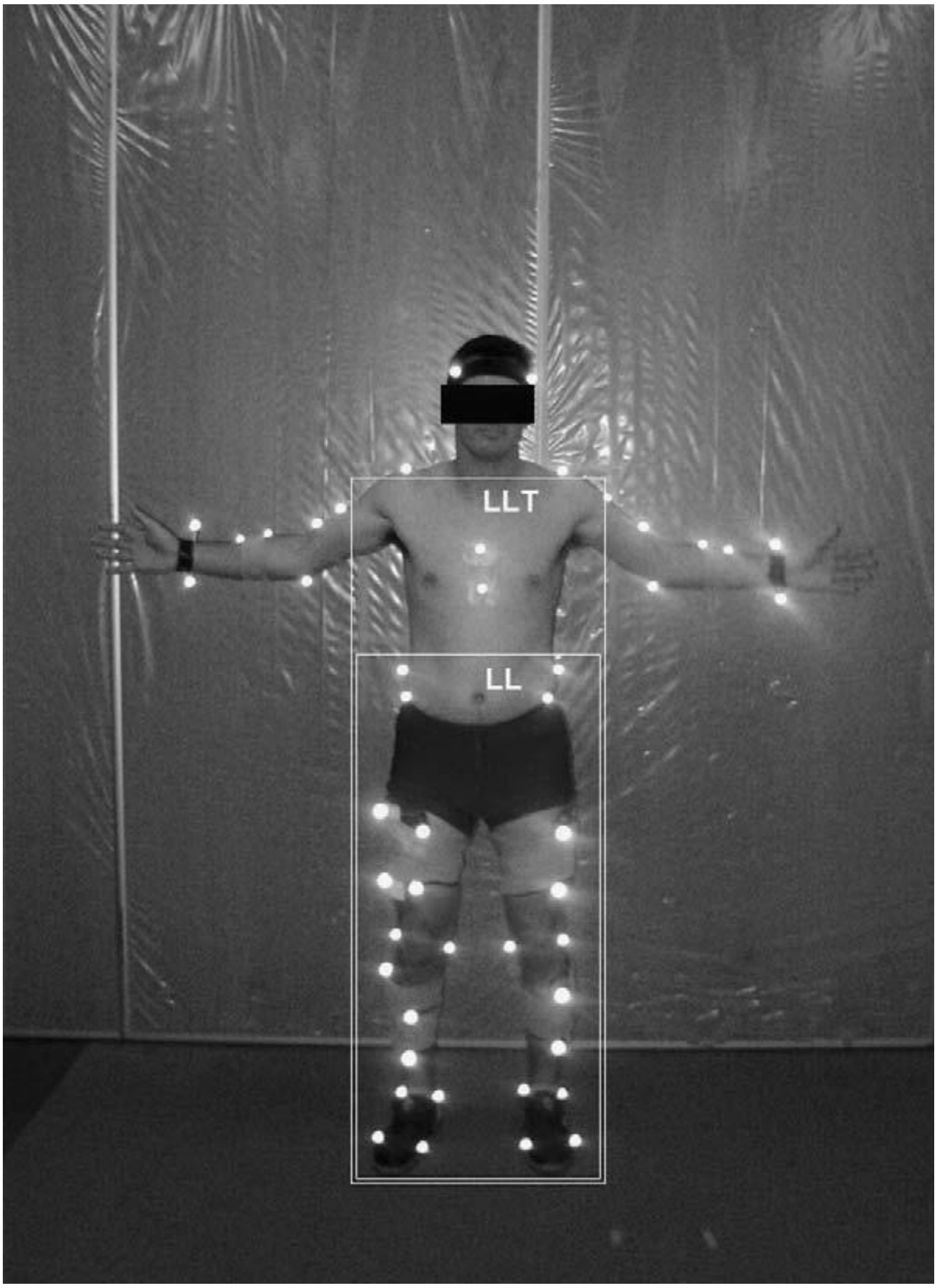
[FT] SQUAD ACTIVITY

Average values for all players involved in 1st team full training or match.

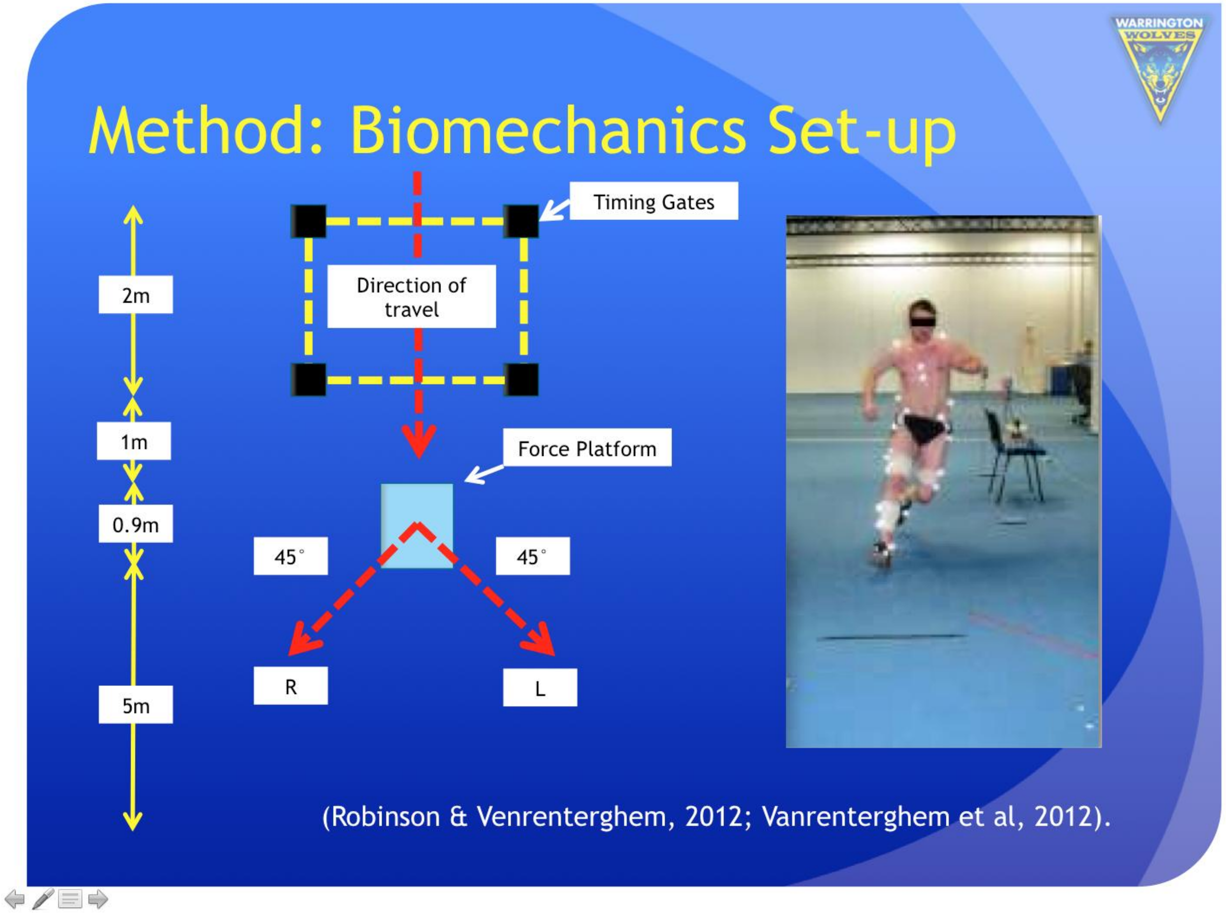
This DOES NOT include any Reserves, 19s, or Loan data - see 10 sheet or individual metric sheets (eg. ACCS %)



Appendix 4: Lower Limb and Trunk Model (Venrenterghem et al, 2010)



Appendix 5: Biomechanics lab set-up.



Appendix 6: Statistical analysis decision tree.